Letters

Comparison of FDTD Computed and Measured Radiation Patterns of Commercial Mobile Telephones in Presence of the Human Head

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***Abstract*— In this letter, finite-difference time-domain (FDTD) computed radiation patterns of mobile telephones are carefully compared with those measured in our laboratory. The question on the capability of the FDTD method to correctly predict the radiated electromagnetic fields of today's structurally complex mobile telephones is addressed. Two commercially available cellular telephones equipped with two different antennas (one helix and one helix monopole) have been considered and the radiation patterns have been measured and FDTD computed with and without the human head. The FDTD computed and measured radiation patterns show good agreement. This verifies that numerical techniques are suitable for accurately modeling radiation patterns of realistic cellular telephones and, more importantly, that the FDTD method is a valid alternative to measurements in the design of new cellular telephones.**

***Index Terms*—Cellular telephones, dosimetry, FDTD, mobile antennas, radiation patterns.**

I. Introduction

The question on the suitability of the finite-difference time-domain (FDTD) method [1], [2] to correctly model today's cellular telephones is often raised because of the complex internal structure and antenna geometry of these devices. Some work has been done in the past to show the capability of FDTD to calculate radiation patterns of mobile telephones [3]–[6], but extensive work on this has never been presented. This topic is of particular interest now that wireless devices must comply with Federal Communications Commission (FCC) guidelines and the FDTD method is considered an acceptable way of verifying this compliance. For this letter, we consider two actual handsets using substantially different antennas in order to show the generality of the modeling capabilities of the FDTD computer code. For these telephones, we consider the radiation patterns measured in our laboratory, both for telephone held in free-space and in the presence of a model of the human head. The measured radiation patterns are compared with FDTD computed results. For one of the telephones, the measured radiation pattern for telephone held in free-space, was also available from the manufacturer and used for comparison as well.

II. Description of the Measurement System

A computer-controlled automated radiation pattern measurement setup has been used to measure the radiated fields of cellular telephones with and without the model of the human head. Model of the head and neck used for the measurements is the previously described Utah heterogeneous model [7] for which tissue-equivalent materials simulating the electrical properties of skull, brain, eyes, and ears have been used. While a KCl-solution-laced epoxy composition is used to form the outer shell of thickness 5–7 mm in the shape of the head and neck, different composition of water, salt, polyethylene powder, and a gelling agent TX 151 (available from Oil Center Research, Lafayette, LA) are used for ear, eyes, and the brain. These materials are semi-solid (with consistencies on the order of thickened jello) so they can be formed in the size and approximate shape of the organs and placed in the phantom skull to provide the lossy phantom model. The cellular telephone and the head model are mounted on a turntable driven by a computer-controlled stepper motor inside an anechoic chamber. The turntable has been adjusted to have 1° rotation movement for each reading, thus giving a total of 360 readings for each radiation pattern. A half-wave dipole antenna is used as a receiver, connected to a spectrum analyzer. It is important to stress that cellular telephones are realistically activated (using test-mode code) in order to avoid external feeding cables that could affect significantly the resulting radiation patterns. Each radiation pattern measurement (either in free space or in presence of the head model) takes about eight minutes.

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III. FDTD Modeling and Results

The model of the human head used in the FDTD code has been described in our previous publications [7], [8]. This model has a resolution of $1.974 \times 1.974 \times 3$ mm and it has been derived from magnetic resonating image (MRI) scans of a male volunteer. Fifteen tissue types have been identified for the model of the head and neck used in our simulations. Since all telephones considered in this paper are calculated at the present mid-band transmission frequency of 835 MHz, the electrical properties of the simulated tissues were taken from the most recent of these properties at 835 MHz. These have been reported in [8, Table I]. For all of the simulations, as well as the measurements, the head and the telephone have been held in the vertical position. Great attention has been given to the accurate modeling of the antenna and the area near the feeding point, while the telephone box has been modeled by a plastic-covered metal box of dimensions comparable to those of the handsets. This is because we have found minimal difference when using an extremely accurate model of the box, while large errors can result by an inappropriate modeling of the antenna and the feeding point. The radiation patterns have been normalized assuming a radiated power of 600 mW root mean square (rms) and they will be reported in dBi. The first telephone considered (telephone no. 1) has a helical antenna having diameter of 4.2 mm, a pitch of 1.4 mm, and a total length of 16 mm. The box dimensions of this telephone are $2.4 \times 5.2 \times 14.7$ cm and the antenna is mounted in one corner of the box. The helix has been modeled as in [6]. The FDTD computed radiation pattern in free-space for this telephone in the horizontal plane is compared with those provided from the manufacturer and measured in our laboratory in Fig. 1. The agreement among the three sets of data is very good and this demonstrates that our measurement system works well, since our measurements in free-space agree well with the FDTD computed and the manufacturer's radiation patterns in the horizontal plane. For the next step, the radiation pattern in the horizontal plane were calculated and measured in presence of the head model. The results, presented in Fig. 2, show that the two radiation patterns agree very well, with small differences likely due to the different head models used for measurements and computations.

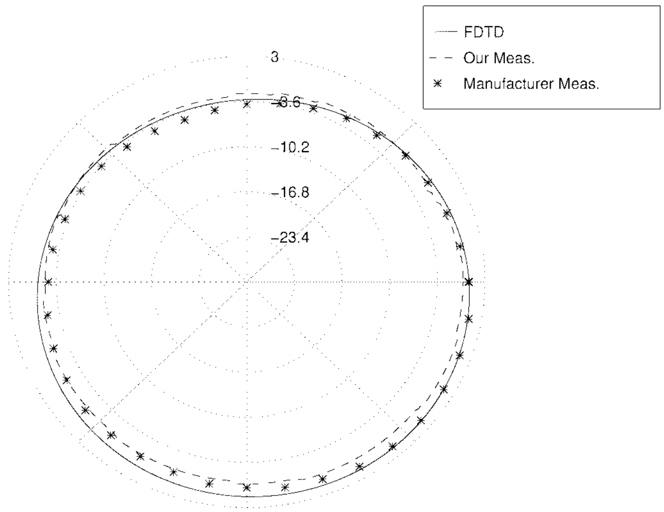

Fig. 1. The FDTD computed and measured radiation patterns (in dBi) for telephone no. 1 in free-space. Also shown are the manufacturer's measurements.

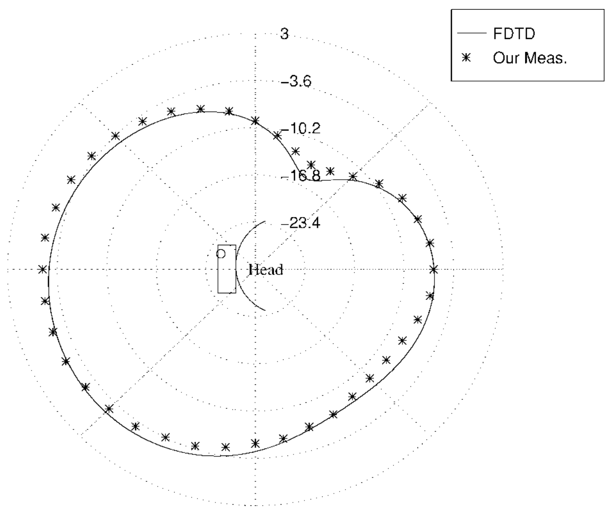

Fig. 2. The FDTD computed and measured radiation patterns (in dBi) for telephone no. 1 in the presence of the human head.

As expected, there is a considerable attenuation in the gain on the side through the human head model. Also, the gain on the side away from the head is somewhat lower because of almost 50% power that is absorbed in the head and not radiated in this case. The position of the node in the radiation pattern is controlled mainly by the position of the antenna above this telephone and the relative position of the telephone with respect to the head model. The second telephone considered (telephone no. 2) uses a helix-monopole antenna. The helix at the bottom has a diameter of 7 mm, a pitch of 3.5 mm, and a total length of 1.9 cm. The monopole, which is pulled out from the telephone box for normal operating conditions, has a length of 10 cm above the helix part. Similar to the previous case, we have found good agreement between measured and computed patterns in air. The radiation patterns in presence of the head for this second telephone is shown in Fig. 3. In this case, also, the agreement between computations and measurements is satisfactory.

IV. Conclusions

In this letter, we have shown that the FDTD method provides accurate predictions of the radiation patterns of commercially available cellular telephones with and without the presence of the model of the human head. Good agreement between measurements and FDTD computations has been presented for two different cellular telephones equipped with two different antennas and similar results have been obtained in our laboratory for several other handsets. These results help in answering the questions on the suitability of the FDTD method as a design tool for cellular telephones. It is concluded that the FDTD method can be successfully used in the design of new cellular telephone antennas, especially for designing antennas exhibiting good gain and low coupling with the human head. Slight variations of the gain, especially in presence of the head model, between simulations and measurements was observed, and is probably due to the difference between numerical and experimental head models. Even with these slight differences, the comparison between measured and numerically computed radiation patterns are well within the acceptable limits.

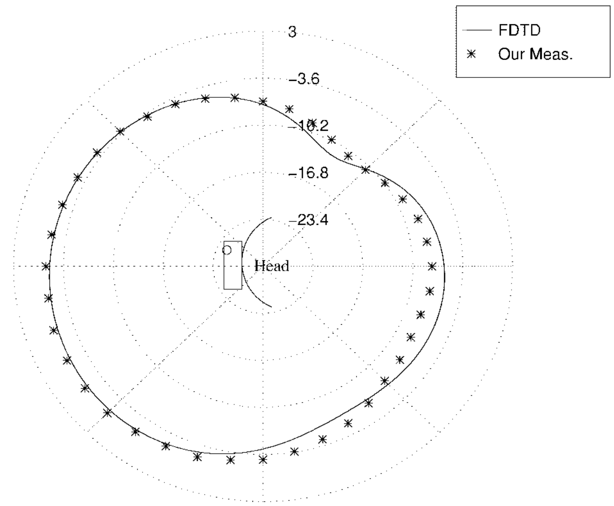

Fig. 3. The FDTD computed and measured radiation patterns (in dBi) for telephone no. 2 in the presence of the human head.

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